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THE MOON AS A SPACE SCIENTIFIC STATION

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THE MOON AS A SPACE SCIENTIFIC STATION

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[Excerpt of Book by N. A. Varvarov, Moskovskiy rabochiy, 1973]

[Text] Will the moon become an intermediate spaceport, linking the earth with other celestial bodies, or will it be used as a base for a space scientific center? Or will both these functions perhaps be combined?

At the present time it is not technically feasible to utilize the moon as an intermediate interplanetary station for outfitting expeditions to deep space. A substantial quantity of fuel will be required for a spaceship to land on and take off from the moon. In addition, on the moon astronauts must be shielded from the vacuum of space, from solar and cosmic radiation, from meteorites, from the extreme heat of the lunar day and from the bitter cold of the lunar night. It is true that when it will be possible to build spacecraft on the moon from local materials and to fuel them with "lunar" fuel, then it will probably be possible to transform the moon into a jumping-off point for space travel. In the near future it is more expedient to employ the moon as a base for accomplishing scientific and technical tasks of an applied nature. What are these tasks?

Weather Forecasting

Thousands of weather stations monitor the earth's weather. Weather forecasts are prepared on the basis of their observations. But meteorologists frequently err. Even short-range weather forecasts are not always correct. Errors in weather forecasts are not due to the lack of competence on the part of the meteorologists. In order to prepare a 24-hour weather forecast for Moscow, for example, meteorologists analyze the development of atmospheric processes from the coast of Africa to the north pole and from the Atlantic to Central Siberia, for the rate of movement of air masses and atmospheric vortices reaches speeds of 100 kilometers per hour and more. Within a 24-hour period they travel more than 2400 kilometers, producing weather changes. Data on atmospheric processes over an even greater area are needed to prepare a weather forecast extending several days.

Preparation of weather forecasts extending a month or several months into the future demands a thorough study of the processes which take place in the earth's atmosphere. Since most weather stations are situated on land, the overall weather reporting network provides sufficient coverage of only one fifth of the earth's surface. The vast water expanses of the world ocean, the polar regions, sprawling mountain ranges, deserts and taiga occupy approximately 80 percent of the surface of this planet and for all intents and purposes are outside the observation of the weather service. This fact complicates the study of atmospheric processes and the mechanism of their interaction on a global basis.

But what if a dense network of observation stations were set up on the continents and hundreds of sea and ocean-going vessels were mobilized for a comprehensive study of the state of the atmosphere? Such a network would still not be utilized very effectively, due to the difficulties of efficient collection and processing of an enormous quantity of weather data received from points scattered all over the globe.

Study of the atmosphere at aerological stations with the aid of radiosondes and the employment of aircraft for weather observations gives us a picture of what is taking place in the atmosphere at altitudes up to 20-25 km. But we know that the atmosphere at higher altitudes also participates in forming the weather.

A very substantial drawback of the weather observations which are conducted at the present time lies in the fact that received data is of an intermittent character, both as regards time and space. Even if weather stations were set up everywhere as in densely-populated areas, at separation distances of not more than 100 km, nine tenths of the world's cloud cover would not be under observation. The quality of those data pertaining to weather phenomena characterized by intermittent and abrupt changes (cloud cover, heavy precipitation, thunderstorm activity) leaves much to be desired. Many details pertaining to the forming and development of weather phenomena escape the notice of weather forecasters. This certainly adds difficulty to both short-range and long-range weather forecasting. Earth satellites have come to the assistance of weather forecasters.

Satellites in the Service of Meteorology

For several years now specialized earth satellites have been doing a successful job of observing the earth's weather. They quickly gather data on the state of the earth's atmosphere. They have equal ease of access to the inhabited areas of the globe and the vast expanses of the oceans and seas, deserts, forests, and mountains of the taiga and polar regions.

Thanks to the instrumentation carried on board weather satellites, we have succeeded in receiving a broad range of data on the state and character of development of weather processes: on the distribution of cloud cover at the moment of observation, on zones of precipitation and areas of thunderstorm activity, on temperatures at the earth's surface and at cloud tops, on the boundaries of snow cover and ice fields, etc. Information received from satellites is immediately utilized for weather forecasting, and this is very important. Satellites, however, swiftly circling a continuously rotating planet, are unable to perform physical investigations for the purpose of increasing our knowledge of the weather processes taking place in a given part of the world.

In order to take numerous photographs of the earth's surface and cloud cover, a large supply of special film is required, but this increases the weight of a weather satellite and requires a higher-thrust rocket to boost it into orbit. Therefore after a picture has been transmitted to earth it is erased from the magnetic film or tape by a special device, and the film can then be reused. There are problems here as well, however: the film deteriorates rapidly, and the quality of the photographs rapidly worsens. These factors limit the possibilities of utilizing earth satellites to obtain information on weather processes in the atmosphere. The moon could be very helpful in the area of weather forecasting.

Weather Center on the Moon

The tasks performed by space meteorology subdivide into two groups. One group involves the acquisition of weather-forecasting information. These tasks will evidently remain the province of earth weather satellites and ground weather stations. Others are focused on extraordinarily interesting physical investigations, which will make it possible to elucidate the features of the circulation of air masses in the earth's atmosphere, to study the effect of solar activity on the weather, and to conduct climatological observations.

From the moon it will be possible systematically to observe how in the earth's temperate latitudes, where westerly winds prevail, cloud masses move eastward, and how at equatorial latitudes constant northeasterly and southeasterly winds move large cloud-cover structures. These structures are the visible manifestation of complex thermodynamic processes taking place in the atmosphere. Clouds are the mirrors which reflect the hidden process of general air circulation in the earth's atmosphere. Colossal air masses, heated in the equatorial zone, rise vertically several kilometers and then proceed toward the polar regions. Cooling, the warm air descends and flows along the earth's surface toward the equator, carrying arctic temperatures to more temperate-climate regions.

The above is a rough description of the cyclical motion of air between hot and cold regions. In actual fact this movement is incomparably more complex. An important role here is played by diversified secondary phenomena. Circulation patterns are quite different, for example, between winter and summer. The continents cool off in the winter and heat up in the summer. The ocean surface, which holds heat longer, is subjected to these fluctuations to a considerably lesser degree. Therefore the continents alternate between being warmer and colder than the ocean. Therefore the movement of air is sometimes from the landmasses to the oceans and at other times the reverse.

The pattern of air circulation in the atmosphere is extremely complex and is not easily analyzed at the present time. A lunar weather center will help determine these patterns, precisely to predict the movement of warm and cold air masses, and, in connection with this, projected weather changes on the earth. It will become a valuable addition to the terrestrial network of weather stations and to the weather satellite network.

Even with the naked eye the observer on the moon will be able to distinguish quite clearly the coastlines of continents, large cloud-cover structures connected with planetary circulation, and snow-covered regions. With the assistance of a telescope with an objective lens 30 cm in diameter it will be possible to examine terrestrial objects as small as a kilometer across if they are appreciably brighter or darker than the background. Image quality will be very good, because the dust-filled, turbulent earth's atmosphere will be not at the observer's end, as when observations are conducted from earth, but at the observed object's end.

One can easily imagine the benefit mankind can derive from still photography, cinematography and TV observation of the earth from the moon. Since the shape and number of clouds and the cloud-cover structure enable one to determine the nature of the processes taking place in the atmosphere, observation of these processes will help predict how the earth's overall weather will change. Analysis of photographs will make it possible to detect the presence of dry or moist air in the atmosphere, to establish the system of air flows, and to determine so-called frontal zones which separate different air masses. Of course at the edges of the earth disk surface details will be obscured by the overlying bluish-white haze caused by the scattering of sunlight in the atmosphere. Even in these areas, however, it will be possible to detect frontal zones by careful photointerpretation.

Very important for marine navigation are iceberg forecasts. After the tragic sinking of the Titanic in 1912, following collision with an iceberg in the fog off Newfoundland, an international ice patrol was organized, which studies iceberg movements in the Atlantic. Special ships and aircraft maintain continuous watch on icebergs calving off the Greenland glaciers, tracking their movement in the Atlantic waters off Newfoundland, through which run the major sea-lanes linking Europe and North America. This effort makes it possible to predict iceberg movements and to issue hazard warnings.

Icebergs and floes are also encountered in other parts of the world ocean. The length of the navigation season in those seas where ice forms depends in large measure on keeping close watch on the ice situation. Of particular importance is a study of distribution of floating ice for Arctic seas. At the present time aircraft and ships maintain ice patrol over a large area. This involves enormous difficulties and is quite costly. A lunar weather station will make it possible to photograph and TV-observe ice conditions. It will be possible to study ocean currents by tracking floating ice.

Photograph of the earth from a distance of approximately 70,000 km. At the moment the photograph was taken the spacecraft was above the Caspian Sea.

Fishing vessels frequently head out for the fishing grounds in the northern latitudes when the ice is just beginning to break up. But a fishing trawler is not an icebreaker; operation in ice-filled waters is hazardous. Ice reconnaissance is essential. It is impractical to send out an aircraft to patrol in an area thousands of kilometers from home shores. It is costly to send out a special ship on ice patrol, and the situation may change by the time it has surveyed the fishing grounds. At the present time helicopters based on several ships of the fishing fleet fly ice reconnaissance missions. But their range is extremely limited. Regular observations from the moon will help solve this problem. From the moon it will also be possible to determine snow-covered zones and changes in the extent of these zones, which is very important in hydrology for predicting spring floods, to spot major forest fires in taiga regions, and to observe the movement of air masses at various altitudes.

A person observing the earth by telescope from the moon will immediately note the prominent sparkling white areas at the poles. As the area diminishes in size at one pole (the snow melts), it increases on the other, and areas showing increasing white gradually link to it (snow-covered forests and fields). The equatorial and tropical regions do not show white but are obscured for extended periods by a blanket of clouds, observation of which will provide much useful information.

An important place in the operations of a lunar weather station will be occupied by both passive and active radiometeorological investigations. Passive investigations are based on the utilization of information which the earth sends to the moon in the form of radio emissions and thermal radiation. An indissoluble link has been established between the processes which take place in the earth "weather machine" and solar activity. Solar radiant energy, passing through the atmosphere, is absorbed and scattered. The earth's surface and atmosphere, heated by the absorption of solar energy, themselves become a source of heat radiation. Investigating with the aid of special equipment the spectral composition of heat radiation escaping into space, one can obtain data on the temperature of the earth's surface, temperature of the air and clouds, vertical temperature distribution in the atmosphere, and on distribution in the atmosphere of such important components for the atmosphere's heat regime as carbon dioxide, water vapor, and ozone.

The atmosphere heavily absorbs the earth's low-frequency radiation. This phenomenon is called the greenhouse effect. Carbon dioxide and water vapor in the atmosphere absorb up to 25 percent of terrestrial radiation, while ozone absorbs up to 20 percent. Since the atmosphere is practically transparent to radiation in the 9-12 micron band, the earth's surface loses heat chiefly in this frequency region.

By measuring the magnitude of the earth's low-frequency radiation, one can determine the temperature of various atmosphere layers. In order to measure the temperature of a given layer, one must have an infrared detector with a set of light filters. Filters which pass emissions in the 3.6-14.7 micron band will make it possible to obtain temperature data on the upper troposphere, in which the bulk of CO_2 and water vapor is concentrated, while temperature in the upper ozone layer can be measured with the aid of filters in the 9.4-9.8 micron band. The obtained data will make it possible to compile "thermal maps" of the earth's surface. The described method is in some respects analogous to spectral analysis, which at the present time comprises the basis of astrophysical investigations of the sun, stars and galaxies.

It is true that in spite of an external similarity, there is a very substantial difference between them. In astrophysics rays of visible light, thermal radiation or radio-frequency waves carry information on the content of given substances in a celestial body, on their concentration, temperature, etc. The earth's atmosphere has been comparatively well-studied. Many average meteorological data for different seasons are known for many regions of the earth. Therefore it is important for meteorologists to know the change of these quantities in time and space, that is that which essentially "makes" weather.

Active methods of radiometeorological investigations are based on study of the changes occurring in a sonde signal when passing through the earth's atmosphere. Both radar and light devices can be employed for such radiometeorological investigations. Radar stations transmitting radio signals (pulses) at specified intervals from the moon to the earth, and then receiving them after they are bounced off cloud cover and returned, will make it possible to study distribution in the earth's atmosphere of rainfall and snow zones, their geometric dimensions and intensity, as well as the location of the boundaries of cloud cover, the height of cloud tops and bases, and to obtain information not only on the distribution of ice in the Arctic but also on ice cap thickness.

The study of solar activity is just as important as continuous observation of the weather processes taking place in the earth's atmosphere. Intensive solar-ray heating of the earth's equatorial-tropical zones generates considerable air exchange between these zones and the colder high-latitude and polar zones. Many scientists believe that circulation of air masses forms the basis of all weather and climate phenomena. If the influence of the sun on the earth remains constant, general circulation of the earth's atmosphere would remain fairly constant. But it fluctuates to a considerable degree. The sun, our great "heat engine" -- operates far from uniformly. The sun breathes as it were, and radiation fluctuates in time to its breathing. Modern astrophysics has established that there exist cyclic fluctuations in solar activity. The duration of the cycles is specified at 11-22 and 80-90 years.

The most clearly-marked solar activity cycle runs 11 years. A solar activity maximum was observed in 1957-1958, and an activity low in 1964-1965. By comparing materials from observations in periods of maximum and minimum solar activity, one can better understand the causes underlying the relationships between solar activity and terrestrial weather. It is extremely important to take into account all energy transformations of solar radiation occurring in the atmosphere for purposes of weather forecasting and climate study. Possessing data on the thermal budget of the earth's atmosphere, we shall be able to predict with reliability changes in air temperature, atmospheric pressure, cloud cover and other elements describing weather and climate.

Space Communications Relay Station

Radio communications on vhf and uhf frequencies, which television broadcasting employs, are limited by line-of-sight restrictions, that is the capability of these radio waves to propagate like the light beam from a searchlight. Since the earth is spherical in shape, and vhf-uhf radio waves cannot follow its curvature due to the intensive absorption by the earth's surface, television broadcasting range on earth is limited by the height of transmitter and receiver antennas. In order to increase the television broadcasting range it is necessary to raise the transmitter antenna as high as possible. Even the Ostankino TV tower, however, which is 537 meters high, has a TV broadcasting radius of only 120-130 km. TV transmission range has been sharply increased with the aid of earth satellites -- the Soviet Molniya-1 and U.S. Telstar communications satellites. It is possible that at some time in the future the earth's natural satellite, the moon, will be utilized for extremely long-range TV broadcasting.

In 1928 Soviet scientists L. I. Mandel'shtam and N. D. Papaleksi theoretically demonstrated the possibility of returning a radar signal from the moon. In the forties many countries began an experimental study of the conditions of reflection from the lunar surface of various-length radio waves, pursuing chiefly astronomical aims: precise determination of distance to the moon, study of the moon's relief, and study of the electrical characteristics of lunar surface rocks.

Between 22 February and 8 March 1964 Soviet and British scientists conducted 13 radio communications sessions via the moon. Radio communications were established between England's Jodrell Bank Observatory and the Soviet Zimenki Observatory, located near Gor'kiy. Each session ran about 1 hour. A signal transmitted from the Jodrell Bank Observatory to the moon would reflect off its surface and return to earth, to Zimenki, in approximately 2.5 seconds.

This technique can be employed to establish vhf-uhf radio communications at distances of up to 10,000 km. It is true that with this technique radio communications can be established only between two points on the earth's surface at which the moon is above the horizon at the moment of radio communications. The basic shortcoming inherent in this type of radio communications becomes obvious: communications are possible only for a limited time each day, and duration of contact diminishes as distance between the communicating points increases.

Unfortunately the moon cannot be used for passive long-range TV transmission because of its spherical shape and sharply-contrasting surface irregularities. Radio signals reflected by the moon are distorted and elongated. It is for all practical purposes impossible to utilize these signals for TV transmissions. Consider what a confusion of sounds occurs in a cave with a loud echo if words are shouted without pause. In order to distinguish what is being said, it is necessary to speak slowly, waiting each time for the echo to die away. Due to the irregularities of the lunar surface, a signal reflected by it contains components with various phase shifts, and as a consequence of the moon's rocking (libration), the phase relations between these components change. Hence radio signals fade rapidly.

Bearing all this in mind, one can conclude that the passive reflection of radio signals from the lunar surface will not be employed for TV broadcasting. For this purpose it is better to employ the moon as an active space communications relay station. If we install on the moon special radio and TV equipment, radio and TV signals transmitted from earth can be received by this equipment and, following amplification, can be retransmitted back to earth.

One can hardly exaggerate the significance of extremely long-range TV broadcasting via the moon for the development of cultural cooperation and mutual understanding among peoples.

Radio and Television Communications on the Moon

The moon's specific natural conditions, absence of an atmosphere, features of motion around the earth, its small size, etc make it impossible to utilize effectively on the moon radio and television communications equipment developed specifically for terrestrial conditions.

We know that low and medium frequency radio waves easily follow the curvature of the earth, and therefore they can easily be picked up with an ordinary entertainment-type receiver from a distance of several thousand kilometers. Due to the high noise level on the moon, however, engendered by the influence of the earth and cosmic radiation, and due to substantial dielectric losses in the lunar soil, utilization of radio waves in these bands on the moon is extremely difficult. As we have stated, it is impossible to employ short-wave radio transmissions on the moon due to the specific features of short-wave propagation. Under terrestrial conditions short-wave signals emitted by a transmitter propagate upward and encounter at an altitude of 100-140 km heavily-ionized atmospheric layers called the ionosphere. The ionosphere reflects back short radio waves, which makes it possible to effect long-range radio communications. The moon has no ionosphere, and therefore this method of long-range radio communications, which is the most widely-employed on earth, cannot be used.

Radio waves in the vhf and uhf bands pass through the earth's ionosphere with practically no reflection. Directed upward, they pass through it and into space. They are close to light rays in their properties, that is they propagate in a straight line, practically without bending with the earth's curvature and around terrain irregularities, on a line-of-sight basis, just as light rays. Due to this exceptionally important property, they have assumed primary importance in space radio communications. The moon's radius is considerably smaller than that of the earth. Due to this fact the lunar surface possesses greater curvature than that of the earth. This greatly reduces line-of-sight range both of optical and radio devices. If they are elevated to a height of 1 meter, line-of-sight range will be about 2 km. They can "see" much further from any hill or other elevated point. From a height of 1 kilometer range increases to 60 km, assuming that no high obstacles are encountered on the path of radio wave propagation. Line-of-sight range increases to 100-150 km at an altitude of 5-6 km. But even from the highest lunar mountain -- Leibnitz Peak -- it is impossible to "see" objects at a distance of more than 180 km. It is necessary to find means and methods which will permit two-way radio and TV communications between scientific stations located at various sites on the moon.

Microwave relay links are employed on earth in order to increase radio communications range. They comprise a line of microwave relay stations located at intervals of 40-60 and sometimes 80-100 km. Distance between stations depends on topographic relief and on the height of the towers on which the antennas are mounted. Radio signals transmitted from a terminal station are directed to the next station in the link, called a repeater station. At the repeater station the signals are received, amplified and retransmitted to the following station, right to the end of the relay link.

Microwave radio communications can be set up on the moon. But since the lunar surface constitutes a sphere with a radius of 1736 km, one can easily calculate that antennas even 50 meters high will not be able to relay a signal more than 25 km. If to this we add that each station must contain its own source of power which must last an extended period of time, as well as reliable remote-control equipment, the difficulties of solving the problem of radio and TV communications on the moon become quite obvious.

Therefore at the present time the idea of artificial satellites is predominant in the area of radio communications. As is well known, Molniya-1 communications satellites are launched into elongated elliptical orbits, which substantially increases their useful operation time -- up to 6 hours per revolution. If a communications satellite is launched into an orbit with an altitude of 36,000 km, its orbital period will be 24 hours. A satellite lifted to a specific point in an equatorial orbit will not change its location but will move at the same velocity at which the earth rotates on its axis. Three such satellites will provide radio and TV communications coverage of almost the entire globe, with the exception of the polar regions.

The idea of extending this technique to the moon is attractive. It is true that the moon's orbital period is not 24 hours but approximately 28 days. Therefore a satellite revolving around the moon in this period should be in an orbit approximately 100,000 km from the moon, which would be possible if the moon and satellite were not subject to the earth's powerful gravitational attraction. A satellite launched into such a high orbit will very soon leave the moon's gravitational field.

But what if a moon communications satellite were launched into an orbit in which its motion would be determined chiefly by the moon's gravitational force? A suitable altitude for this is 4800 km, while the satellite's orbital period would be about 12 hours. It would be moving around the moon much faster than the ground scientific stations. Continuous communications among lunar-surface stations would require at least 10 satellites.

Satellites launched to libration points, that is points where gravitational forces are balanced by centrifugal forces, will probably work out well. Calculations indicate that two satellites positioned at mean distances of 65,000 and 58,000 km from the moon will be able to provide radio and TV communications for lunar scientific stations. But in order for these satellites to remain continuously at the libration points it would be necessary periodically to correct their position in space. Today this problem no longer appears particularly difficult. It can be resolved with the aid of hardware we presently possess.

Laboratories on the Moon

A characteristic feature of modern technology is the increasing utilization of processes and phenomena which are of a space-environment nature, such as ultrahigh and ultralow temperatures, ultrahigh pressures and vacuum, plasma state of matter, powerful radiations and physical fields, etc. Forces in space are more powerful than those which are specifically terrestrial. Mastery of these forces will open up practically unlimited possibilities for achieving technological advances and for man's conquest of nature.

One important task of metallurgy and machine building is the development of totally new materials capable of withstanding ultralow and ultrahigh temperatures, the effects of cosmic radiation, the vacuum of space and other conditions prevailing in space and on the moon. The so-called transition metals, for example, are studied at low temperatures and in a vacuum: titanium, scandium, chromium, manganese, iron, and the rare-earth metals. New machines are designed and built of many of these materials. The transition metals, their alloys and compounds constitute the basis not only for the hulls of manned spacecraft but also for new high-powered machine tools and automatic production lines.

The properties of the rare metals and their alloys have been little studied. It is impossible to make an alloy of the required composition or to obtain a pure metal with conventional methods: in a molten state the rare metals and their alloys are chemically extremely active. For example, an attempt to melt tantalum or niobium in a vacuum, placing them in crucibles of oxides of beryllium and thorium, which are indestructible from a chemical and temperature standpoint, was a failure. As soon as the tantalum and niobium were heated, the crucibles became transformed into a porous metal, while the tantalum and niobium, taking oxygen from the crucibles, became oxides. An alloy must be heated in such a manner that it does not come into contact with any chemical elements. The moon's reduced gravity and high vacuum will facilitate solution to this complex problem.

A high vacuum is extremely important for many industrial processes. It requires an enormous effort to create a high vacuum on earth. In space and on the lunar surface nature itself has created ideal high-vacuum conditions. "We cosmonauts," stated Yuriy Gagarin, "due to the nature of our profession, perhaps encounter chemistry in all its miraculous manifestations sooner than anybody else. Take, for example, the fuel which propels our rockets; take the alloys and metals of which they are fabricated; take our space suits and all the other products with exclusively space applications -- thousands upon thousands of large and small items which surround man on his journey into space. Everywhere you will encounter chemistry. The agenda of the conquest of space includes more magnificent tasks than those we have accomplished up to the present time. The agenda includes flying to the moon, to other planets in our solar system, travel beyond the solar system, and the establishment of contact with other worlds. But this will require new speeds, new spacecraft, new equipment, and new fuels. And all this will require chemistry, new materials which are better than those which we possess at the present time."

Conditions on the moon will make it possible to perform unprecedented physicochemical experiments, with the aim of deeper penetration into the structure of matter. The study of cosmic radiation and its effect on natural substances and synthetic materials can open up new horizons of radiation-chemistry and radiation-physics technology, particularly radiation metallurgy. Investigations in the area of high-vacuum technology and electronics, as in many other areas of science and technology, may prove exceptionally fruitful. The moon's size, its reduced gravity, and the possibility of rigid mounting of scientific research equipment on the lunar surface substantially simplify the technical problems of placing large facilities on the moon. Utilizing the moon's vacuum, it will be comparatively simpler than on earth to organize production in the flawless growing of large single crystals, which are the basis of transistors and lasers.

The moon may become a reliable scientific base for solving many problems of biology and medicine. Take the following example. All living organisms depend on such an external environment factor as gravity. The determining role of gravitational forces in the life of organisms was stated for the first time by K. E. Tsiolkovsky in 1925 in his essay "Biology of Dwarfs and Giants." In his opinion the size of organisms is determined by the gravity on the surface of a celestial body. If life similar to that on earth developed on the moon, all living beings would be 6 times larger than on earth; on the other hand only dwarfs could live on Jupiter, where gravity is 2.6 times greater than on earth. D. V. Thomson has claimed, for example, that if earth gravity were increased, the representatives of the majority of terrestrial forms would be like short-legged fossil reptiles, while with a reduced gravity, cut in half, for example, they would become light, thin, more active and would expend less energy.

At the present time we are unable to test the correctness of these assumptions with direct observations of living organisms. There is no doubt, however, that on the moon, under conditions of greatly reduced gravity, such a test could be performed, as well as investigations connected with the influence of cosmic radiation and the moon's absence of an appreciable magnetic field on plants and animals. The tasks of biologists and medical specialists will include the search for living organisms on the moon and problems pertaining to the survival of terrestrial living matter on the lunar surface. On the moon man will be able to prepare himself in a medical and biological respect for longer space journeys.

Unusual Observatory

We have already stated that the earth's atmosphere is viewed by astronomers, astrophysicists and radiophysicists, in short by all specialists who study the world of space, as a great hindrance to their work. Air, which seems absolutely transparent to us, constitutes an insuperable barrier to the bulk of radiation reaching us from space. Only components of two small bands in the electromagnetic wave spectrum freely pass through the atmosphere: light rays and radio waves in a band from several millimeters to 30 meters. The atmosphere is opaque to the rest of the spectrum. A portion of the ultraviolet rays, X-rays and gamma rays from the sun, long-wave radio emissions, primary cosmic and many other rays do not reach the earth's surface, and yet a substantial portion of solar corona radiation falls precisely within the ultraviolet region and the long-wave band.

Radiation of the planets reaches a maximum in the far infrared region of the spectrum, the rays of which are absorbed by the earth's atmosphere. Very hot stars are bright in the ultraviolet region of the spectrum. Interstellar dust emits in the infrared band. Recently discovered stars and galaxies "shine" only in X-rays, which are totally absorbed by the earth's atmosphere at an altitude of more than 100 km. These and other regions of the electromagnetic spectrum which are inaccessible to observation from earth contain, scientists believe, extremely important information on the root problems of the universe, connected with the origin of stars and star systems and with the nature of the prestellar state of matter. It is understandable that the investigation of celestial bodies through narrow windows of atmospheric transparency extraordinarily impoverishes the picture we receive of processes taking place on them. From the moon it will be possible to investigate the entire spectrum of electromagnetic emissions.

As a consequence of the atmosphere's optical inhomogeneity (continuous movement of air, differing air density and contamination), it is impossible to magnify objects observed by telescope from the earth by more than 400-500 times. The greater the magnification, the greater the effect of movement of air currents on the quality of the image. The earth's atmosphere mantle reduces the apparent brightness of stars, causes them to twinkle, and as a result of this produces vibration and blurring of star images on telescope photographic plates.

Since the intensity of the light flux from celestial bodies is extremely low, very long exposures are necessary when photographing planets, stars and galaxies. These exposures run into tens of minutes and even hours, during which luminous energy accumulates on the photographic plate. The flickering of the light ray, however, results in an indistinct, blurred image on the photographic plate. Therefore an extended exposure cannot be permitted when photographing celestial bodies from the earth through a telescope. Of course this situation does not entirely extend to high-mountain observatories, where the air is cleaner and more transparent.

Sometimes experts are asked: "What are the magnification capabilities of modern telescopes?" Theoretically it is easy to obtain magnifications of 3000-5000 times and greater, but for practical purposes such magnifications are useless, since they produce blurred and wavering images. The fact that huge telescopes are constructed is not for the purpose of greater magnification but rather to gather more light for photography and spectrography of weak and distant celestial objects. But it is impossible to build on earth telescopes with a very large-diameter objective lens or mirror. Maximum mirror diameter should not exceed 6 meters, while maximum objective lens diameter should not be greater than 1 meter. A larger-diameter objective lens or mirror will sag under its own weight.

On the moon, where there is no atmosphere, no wind loads, and where gravity is one sixth terrestrial, it will be possible to set up telescopes with comparatively small mirrors and objective lenses, which will make it possible to obtain a substantial magnification of observed objects and to employ any length of exposure. Even a small telescope with a mirror only 1 meter in diameter on the moon will be equivalent to a terrestrial telescope with a mirror 5 or 6 meters in diameter.

Astronomers wait for years to witness such a rare phenomenon of nature as an eclipse of the sun. The last eclipse of the sun visible at several locations in this country as a total eclipse took place on 22 September 1968. The next total eclipse of the sun which can be seen in the USSR will take place on 31 July 1981. Usually a total eclipse of the sun can be observed for a period of only 2 or 3 minutes. On the moon, as we have already stated, it will be possible to create an artificial eclipse of the sun at any time of day and to observe it as long as desired. This is very important, for it will be possible continuously to study the dynamics of the processes taking place on the sun and to study in greater detail the phenomena taking place above the solar photosphere -- in the chromosphere and in the solar corona. Thus it will be possible to determine more completely and precisely the physical essence of the processes taking place on the sun and to determine the nature and intensity of radiations deriving from each layer.

Why can this not be done from the earth? Block the sun with some kind of shield, and you have an eclipse. Naturally it is possible to block the sun from our eyes or the telescope lens, but it is impossible to shut out the sunlight-illuminated air -- this would require placing a shield outside the earth's atmosphere. The moon, of course, becomes just such a shield during an eclipse of the sun. But since there is no air on the moon, a small dark shield is sufficient in order to observe an eclipsed sun from the moon.

A lunar observatory will make it possible to obtain much new data on other celestial bodies and on space. Its instruments will receive radiations across a vast waveband -- from one hundred-millionth of a centimeter to thousands of kilometers. The structure of our star system and the structure of other galaxies will be studied in detail. Processes taking place in interstellar space will be presented in full array to scientists. The lunar observatory will be able to receive without obstacle cosmic rays and corpuscular fluxes in the entire diversity of their spectra, from any source or direction.

The Sun-Earth Problem

In an ancient Egyptian temple archeologists came upon a drawing depicting the sun. The artist, who had lived 3000 years ago, portrayed it in the form of a convex disk surrounded by rays. Each ray descending to earth terminated in a human hand. Yes, we earthlings are bound to the sun by firm bonds. The earth reacts sensitively and obediently to each and every solar "sigh." The sun is the earth's energy base. The sun warms and illuminates it. Life develops and is supported on earth thanks to the sun's rays. Extinguish the sun and our entire planet would become transformed into a lifeless block of ice.

More than 200 years ago English astronomer Sir William Herschel noted a paradoxical link between sunspots and the price of grain and wool. Every 11 years grain harvests declined, and the price of grain and wool rose. We now know that every 11 years a period of increased solar activity occurs, ending with a decline. Giant flares occur on the surface of the sun, as a consequence of which streams of incandescent gases leap hundreds of thousands of kilometers upward toward interplanetary space. On 2 September 1967, for example, one of the largest recorded solar flares was observed for a period of 2 hours. A similar phenomenon was recorded at a somewhat earlier date, on 23 February 1965. Echoes of these flares reach our planet very rapidly. A sharp increase in the earth's atmosphere of a flux of fast-moving particles -- ions, electrons, protons, etc -- produces the aurora borealis, causes powerful magnetic storms which disrupt radio communications and distort the readings of magnetic navigational instruments, and exerts appreciable influence on the climate and weather.

It has been established that giant explosions in the inner regions of the sun and tumultuous processes in its outer regions lead to ejection from the sun of clusters of so-called corpuscles -- charged particles. Plasma fluxes, which have been given the graphic name "solar wind," surge into space from the sun. The "solar wind" consists chiefly of protons -- positively-charged hydrogen nuclei moving at a velocity of approximately 1000 km/sec. Reaching the earth's atmosphere, the "solar wind" affects the temperature and motion of the upper atmosphere.

Just as primary cosmic rays, the "solar wind" must definitely cause erosion of the lunar surface and blow away those particles which could form a lunar atmosphere. It produces the accumulation of an appreciable positive charge in the lunar surface materials. It is believed that the positive charge on the lunar surface material may diminish the heat conductivity of the moon's surface layer. It is quite understandable that from the earth it is impossible carefully to examine the influence of the "solar wind" on our planet's atmosphere and on the moon. This can best be done on the moon.

We know that the idea of nuclear energy was developed through study of the sources of solar energy and cosmic rays. And the idea of thermonuclear reactions involving hydrogen occurred when scientists were studying the mechanism of energy release deep inside the sun. What can knowledge of the processes taking place on the sun provide to physicists? A good deal. At the present time high-energy particles are obtained with the aid of special accelerators, which comprise immense electromagnets weighing tens of thousands of tons, with a huge number of complex mechanisms. The world's largest accelerator recently went on line in the Soviet Union; this facility can be used to obtain particles possessing an energy of 76 billion electron volts. For comparison we might mention that particles of air at room temperature possess an energy of about 1 electron volt. Soviet physicists are convinced that particles with an energy of up to 400 billion and possibly as much as 1000 billion electron volts can be obtained with accelerators. Nevertheless the world of space is increasingly drawing the attention of physicists. In recent years scientists have succeeded in recording in cosmic rays particles with an energy close to 10^{20} electron volts. This is billions of times greater than that produced by today's biggest accelerators.

Cosmic rays will remain for a long time to come the sole source of particles possessing energies many orders of magnitude greater than those which man creates on earth. Investigation of such high-energy particles on the moon will make it possible to advance man's knowledge of the properties of matter and will lead to qualitatively new discoveries.

By studying phenomena which take place on the sun we can gain an idea of those processes which have occurred on other stars as well. In that natural solar laboratory, the closest one to us, we can study the behavior of matter under conditions of immense pressures and extremely high temperatures, for deep within the sun pressure exceeds 10 billion standard atmospheres, while temperatures reach 5,000,000°. At present such conditions cannot be created on earth. Their study not only will help us gain greater knowledge of the phenomena taking place on the sun and other stars but will also advance terrestrial power engineering.

On 18 August 1868 French astronomer Jules Janssen observed multicolored lines on the limb of the sun with the aid of a spectroscope, during a total eclipse of the sun. Among the diversity of already-known lines he noted a new, light-orange line. It could not be caused by any substance known at the time. Janssen continued his investigations without waiting for another eclipse of the sun. His observations and simultaneous observations by American scientist Norman Lockyer suggested the conclusion that the sun's atmosphere contained an unknown gas. It was given the name helium (from the Greek word "helios" -- the sun). In 1881 helium was discovered among gases venting from Mount Vesuvius, and in 1905 helium was obtained from a mineral called cleveite.

We should not exclude the possibility of similar discoveries in the future. Due to the limited nature of that segment of the solar spectrum accessible to investigations from the earth's surface, elements on the sun have been identified with earth elements in only 60 percent of cases. Observations from the moon will help identify the remaining 40 percent of solar elements with earth elements and possibly will help discover new chemical elements unknown to us up to the present time.

Flares and explosions on the sun remain a puzzle, in spite of the fact that they have been studied since Galileo's time. It is believed that magnetic fields play an important role in all manifestations of solar activity connected with the motions and ejection of charged particles. With the aid of a special instrument -- the solar magnetograph -- it will be possible to study the sun's magnetic field from the moon. This will enable us to verify a hypothesis of Soviet astrophysicist A. B. Severnyy, who claims that solar flares occur as a result of a unique rapid compression and collapse of magnetic fields, which lead to the impulsive heating of a small region of solar gas to a temperature in the vicinity of 5,000,000°.

Study of the composition of the energy spectrum of solar and cosmic radiation is acquiring enormous practical importance in connection with the development of manned space exploration. From time to time space is penetrated by radiation lethal to living organisms, as a result of eruptions or explosions on the sun. Particularly intensive fluxes of solar protons have an adverse effect on spacecraft electronic equipment. In addition plasmoids, separating from the sun and wandering in circumsolar space, possessing a very high temperature, can literally vaporize a spacecraft. Without studying these phenomena we cannot develop means of protection against them, nor can we embark upon extended manned space ventures.

Observatories in the Soviet Union are maintaining continuous observation of solar activities. The slightest suspicious changes are immediately reported to the Sun-Earth Scientific Council at the Academy of Sciences USSR Institute of Geomagnetism, the Ionosphere and Radio Wave Propagation (IZMIRAN). Information reported to the council is immediately transmitted to Washington, Tokyo, Australia, France, Czechoslovakia, and West Germany. Foreign scientists also inform their colleagues on the sun's behavior through their own regional centers. When increased activity is noted on the sun, the geophysical alert signal sounds around the world. At this signal geophysical rockets are launched, observatory domes open, and telescopes are trained on the sun. There is no question that lunar observatories will in time occupy an important place in solar service activities.

Investigation of Other Planets from the Moon

"Fortunate is he who has seen the planet Mercury," say astronomers. The closest neighbor of the sun, Mercury is usually obscured by its blinding light. At times it does move away from the sun, but not more than 28°. At such times, just before dawn or just at the end of dusk it can sometimes be seen briefly, as a yellowish, comparatively bright star. Even this observation is not satisfactory, however, since Mercury does not rise high above the horizon and must therefore be viewed through the dust-laden, turbulent atmosphere. The small angular dimensions of Mercury's disk and its position at a comparatively close distance from the solar disk make telescopic observations very difficult.

The brightest celestial body after the sun and moon is Venus. But it is also difficult to observe Venus from the earth: when it is closest to the earth it is situated directly in front of the sun, which illuminates the side opposite earth. Situated somewhat eastward or westward of the sun, Venus appears as a narrow crescent. Only beyond the sun is it visible as a full disk. But at this time the distance to Venus is twice as great and, in addition, it is obscured in the sun's rays. Venus is not long visible from earth, either just before dawn or in the early evening hours. It is enveloped in a dense, cloudy atmosphere, and therefore its surface cannot be visually observed. The clouds reflect a substantial portion of the sun's rays incident on the planet. This explains Venus's brightness.

From a lunar observatory Venus and Mercury could also be observed when they are closely aligned to the sun, not only when they are out of the rays of the solar corona. They could be observed during the lunar morning, before sunrise, in the afternoon, and in the evening, after sunset. Mercury's brightness will exceed that of the brightest star, while Venus will be brighter than all celestial bodies other than the sun and earth. Its brightness is at times so great that the terrestrial observer can see shadows from the objects illuminated by it. Imagine how bright Venus will appear from the moon!

Since the orbital planes of Mercury, Venus, Mars, Jupiter and Saturn -- the planets which are visible with the naked eye -- are inclined at small angles to the plane of the ecliptic (the maximum angle of inclination is that of Mercury's orbital plane, at 7°), they will all be almost always visible from the moon's north and south poles. The absence of an atmosphere will make it possible carefully to examine not only these but other planets of the solar system as well without the obstacles which are so annoying when making terrestrial observations.

From earth we can distinguish craters on the lunar surface with a diameter of 50-100 m, and on Mars features 8-15 km across. Larger features are visible on many planets further from the earth: on Jupiter -- 80-160 km, on Neptune -- 800-1600 km, while at times it is even difficult to distinguish Pluto's disk. Now let us imagine a telescope with a mirror diameter of 1-2 meters, mounted on the moon. Image sharpness is excellent, so that even a planet such as Pluto can be examined in detail. We should note that from the moon it will be possible to view Mars even with the naked eye as it is visible from earth through the finest telescopes at opposition.

Studying the planets from the earth, astronomers cannot always precisely determine which of the obtained data are determined by the earth's atmosphere and which by the atmosphere of the target planet, due to the fact that the spectral bands of some components of the earth's atmosphere are superimposed on the spectral bands of the same components of the target planet. This will not occur during planetary observations from a lunar observatory. On the moon it will be possible to perform spectroscopic and other investigations across the planets' entire electromagnetic radiation spectrum, which cannot be done from the earth.

Finally, as we have stated above, on the moon it will be possible to obtain any desired magnification of observed objects and to employ any length of exposure in photographing them. This will help, for example, in solving the puzzle of the Martian canals, which some believe to be fractures in the Martian crust, others take to be vegetation, while others take to be a series of small features merging into solid strips for the observer situated at a great distance from Mars; still others consider them to be Martian-made structures. A lunar observatory will make it possible to obtain much new information on the planets of the solar system.

The Secret of Faintly-Luminous Objects

On a moonless night in the spring and fall, when the ecliptic rises high above the horizon in the earth's southern latitudes, just after sunset or just before sunrise, in the southern skies one can observe a conical silvery glow extending in the direction of the sun. It is so weak that even the faintest stars are visible through it. Since the axis of this glow lies in the plane of the ecliptic and passes through zodiacal constellations, it has been called the zodiacal light.

The brightness of the zodiacal light somewhat increases on particularly dark nights in the region of the heavens opposite the sun. A faint elliptical spot can be seen at this time at the point of the zodiacal cone. Since it is diametrically opposite the sun, it is called the gegenschein. It has been noted that as the sun passes through the zodiacal constellations, the gegenschein is also displaced. When at the end of the year the sun returns to the initial zodiacal constellation, the gegenschein also completes its journey along the zodiacal belt.

What is shining there in the depths of the night sky? The hypothesis has been advanced that the zodiacal light is caused by cosmic dust diffusing sunlight. The rays of the setting sun are scattered by tiny particles of matter wandering in space. This phenomenon is similar to the way invisible dust particles are picked up by sunbeams entering a room.

On the basis of the luminosity of the zodiacal glow, scientists have established that although the concentration of interplanetary dust is extremely small, it is essential to investigate it in the age of space travel, for at the high speeds attained in space flight even minuscule particles, with a mass of millionths of a gram, are capable of damaging the skin of a spacecraft on impact, just as pebbles shatter the windshield of an automobile traveling down a highway. Therefore instruments to record meteoritic particles are carried on board artificial earth satellites and deep-space probes. The results of these experiments have shown that these particles occur in substantially larger quantities near the earth than at great distances from it. For some reason cosmic particles are concentrated in the vicinity of our planet.

Academician V. G. Fesenkov established an important feature of the zodiacal glow. It seems that the zodiacal light spectrum constitutes a greatly-attenuated copy of the solar spectrum. It is therefore assumed that this glow is nothing other than reflected sunlight. Reflected? But from what? From tiny meteoritic dust particles or from the molecules of some gas? Interplanetary space, in addition to meteoritic material, is filled with gas molecules and atoms and various kinds of radiation. Soviet scientist I. S. Astapovich has reached a very interesting conclusion. He believes that a gaseous sleeve-like structure consisting of a flux of molecules or, more precisely, dissociated atoms, similar to the tail of a comet, extends from the earth's outer atmosphere in a direction away from the sun.

Academician Fesenkov, who has dedicated many years to the study of this puzzling glow, confirmed the Astapovich hypothesis after taking a great many measurements of the luminosity of the zodiacal glow, performed both in the southern part of the Soviet Union and in Egypt. He believes that the elliptical shape of the gegenschein is probably caused by the flattened nature of the earth's atmosphere in a direction perpendicular to the earth's orbital plane. The luminous gaseous tail evidently consists of a flux of gas particles escaping from the earth's uppermost layers of atmosphere as a result of sunlight pressure on it. Gas particles are also driven away by the "solar wind."

This hypothesis immediately attracted the attention of scientists. Repeated, painstaking spectral analysis confirmed the direct link between the gaseous tail and the earth's atmosphere. This was confirmed by investigations conducted from artificial earth satellites. According to the most recent data, the earth's gaseous tail extends approximately 100,000 km. These data, however, must be subjected to further verification, since they are based on observation of difficult-to-observe phenomena.

It is very difficult to perform detailed observations of the solar corona and zodiacal light from earth. At distances of 7-7.5° from the sun, parts of the solar corona cannot be observed, while the zodiacal light can be observed at a distance of 60-80° from the sun. This hinders establishment of proof of their common nature. From the moon it will probably be possible to observe the zodiacal light and the earth's gaseous tail, the gegenschein and outer regions of the solar corona in their pure form. Then it will be possible to determine the true nature of faint-luminosity objects.

Does a Trans-Plutonian Planet Exist?

In March 1930 the world learned of the discovery of the outermost planet of the solar system -- Pluto. Since this planet is quite distant from the earth and is very small, scientists know little about it at the present time. In the fifties scientists succeeded in measuring the angular diameter of its tiny disk. The planet's diameter proved to be 5870 km, that is 0.46 the size of the earth's diameter. Thus Pluto occupies a n intermediate position in size between Mercury and Mars. Its orbital plane is inclined at an angle close to 17° to the plane of the elliptic, while its orbit is so elongated that at times it approaches the sun to a closer point than Neptune. Pluto's mass was computed on the basis of various irregularities in the orbital motion of the planet Uranus. Pluto's mass is close to that of the earth. Consequently the planet's average density must be incredibly high, approximately 50 g/cm^3. This means that Pluto is comprised of matter the density of which is 6 times greater than that of steel! But that is impossible. Pluto proved to be something quite different from the expected "Lowell's planet" -- a gaseous giant with a mass 6 times greater than Pluto actually possesses. In view of Pluto's gravitational force, experts concluded that the perturbations in the orbital motion of Uranus must be caused by a more distant, tenth planet.

Scientists have linked the highly complicated motion of Uranus with a hypothetical planet located beyond Pluto's orbit. If such a planet exists, it would explain several perturbations of Uranus. And Pluto's mass would be much smaller. Astronomers have computed that this tenth planet, which they have named Trans-Pluto, is approximately 77 astronomical units distant from the sun and has an orbital period of 676 years. Its orbital plane is inclined 38° to the plane of the ecliptic. Therefore Trans-Pluto must be sought not in the zodiacal belt of constellations but rather in constellations where the other planets are never found. But it will be very difficult to spot it among the star field of other constellations, since it must move very slowly. In time the telescopes of a lunar observatory will make it possible to examine the celestial sphere in greater detail, with the aim of locating the hypothetical Trans-Plutonian planet.

Beyond the Solar System

Up until quite recently the main feature on the basis of which scientists determined the state and character of any celestial body was its emission spectrum. This was the sole bridge linking us with distant luminous bodies. During the three and a half centuries of its existence, optical astronomy has penetrated deep into the universe. Suffice it to say that with the world's largest reflector telescope, with a mirror diameter of 5 meters, located at California's Mount Palomar Observatory, scientists can observe galaxies 2 billion light years distant. We might recall that light takes only 8.5 minutes to reach the earth from the sun. With the aid of telescopes and spectral analysis astronomers have succeeded in determining the chemical composition of the surface layers of the sun and stars, have studied the motion of celestial bodies and have resolved many other questions.

Scientists have penetrated much deeper into the universe with the aid of radio telescopes -- a distance of 10-12 billion light years! But the advantage of radio telescopes lies not only in their long range. They help study many processes taking place in celestial objects which are concealed from optical means of observation. With the aid of optical telescopes astronomers have been able to examine approximately 10 percent of the total volume of our galaxy. The rest of the galaxy was inaccessible to visual observation, since it is obscured by clouds of interstellar dust. But these clouds are transparent to radio waves. Investigation of cosmic radio emissions has made it possible not only to penetrate into the galaxy's central region but also to determine in greater detail the structure of the metagalaxy and to gain knowledge of the complex processes taking place within the vast cosmic formations in the universe.

Among the stars there exist so-called variables, that is those which alter their state. Most interesting and deep-lying processes are taking place within these stars, connected with the release of immense quantities of energy, inconceivable under our terrestrial conditions. The cause of this phenomenon is as yet unclear. "We encounter such phenomena," states prominent Soviet scientist B. V. Kukarkin, "in studying supernovae. But we do not possess knowledge of the most interesting radiations of the supernovae -- ultraviolet, X-radiation, gamma radiation -- in their original state, undistorted by our atmosphere. The placement of equipment on the lunar surface to maintain continuous monitoring of supernovae will enrich science with valuable information on processes taking place in the universe. Perhaps in time scientists will find the key to the gigantic energy processes of the supernovae. It may be possible that they can be reproduced in terrestrial laboratories, of course taking all possible precautionary measures. This discovery will prove to be a revolution in power engineering."

About a quarter of a century ago Soviet scientist Academician V. A. Ambartsumyan discovered star systems of a new type -- star associations. This discovery confirmed the theory of a continuous process of star forming in our galaxy. Study of star associations has shown that many of their features stand in clear contradiction to the hypothesis which has held total hegemony in science up to the present time, which claimed that stars are formed as a result of condensation of gaseous matter or dust particles.

A new hypothesis was advanced on the forming of stars from massive high-density bodies -- protostars. But protostellar bodies cannot be seen from earth -- they are in a stable state and do not indicate their presence in the conventional manner. The moon will probably offer an opportunity to investigate them.

X-ray Telescope on the Moon

The scientific experiments performed by the Lunokhod 1 vehicle included the investigation of X-radiation from deep space. The first attempt to pinpoint sources of X-radiation in space was undertaken in 1962, when a group of American scientists performed an experiment to measure the moon's X-radiation which, in their opinion, could be caused by bombardment of the lunar surface with cosmic rays.

They did not succeed in recording lunar X-radiation, but they did make one of the outstanding discoveries of the 20th century -- they discovered discrete sources of X-radiation in space. With the aid of a rocket launched at night, when solar radiation could be discounted, two prior-unknown X-radiation sources were discovered: a powerful source in the constellation Scorpio, and a much weaker source in the constellation Taurus. There were neither moon nor planets on the rocket's path; consequently the radiation sources were outside the solar system (it is true that Soviet lunar satellites did detect weak lunar X-radiation). In recent years approximately 100 such sources have been discovered, several dozen of which have been identified with known optical objects. The identified sources include 10 extragalactic (situated outside our galaxy) objects. Giant explosions accompanied by the ejection of clusters of matter and magnetic fields occur in the depth of these galaxies with active nuclei. The X-radiation emitted by these galaxies is several times greater than radiation in the radio-frequency band, and therefore they can essentially be called X-ray galaxies.

Some X-ray sources are identified with quasars. Quasars were first discovered quite recently. They are the most powerful of presently-known generators of energy in the universe. Situated at enormous distances from one another -- measured in billions of light years -- they enable us to investigate the universe at early stages of its development. The closest of the discovered quasars is one and a half billion light years distant from our galaxy. This quasar emits 10,000 times more energy than our entire galaxy, while its diameter is only 1000 astronomical units, that is it is 1 million times smaller than our galaxy. Where do the quasars derive such great energy? What is their structure? It is extremely important to obtain answers to these questions, for elucidation of the nature of quasars may lead to the discovery of new physical laws.

Since X-radiation does not pass through the earth's atmosphere but is absorbed at altitudes above 100 km, it was impossible to observe quasars prior to the development of rockets and earth satellites. But rocket observations are limited by the brief duration of their flights, while observations from satellites are limited by their high speed. In addition, the X-ray flux which reaches the earth from quasars is very weak, which also makes their study difficult. Up to the present time scientists have not succeeded in determining even the coordinates of the majority of quasars in the celestial sphere with sufficient accuracy to state that any one of them coincides with a given star which has been examined by optical astronomy.

The X-ray telescope mounted on the Lunokhod can store radiation in its "brain" -- for the moon completes one revolution relative to the celestial sphere every 27.3 terrestrial days. Since an X-radiation source in the field of view of the X-ray telescope's photon counter, comprising 3°, moves only 1 second of arc in 2 seconds of time, the source remains in the field of view for approximately 6 hours. This observation time is approximately 1000 times greater than is possible with rocket experiments. By observing the rising and setting of celestial bodies emitting X-radiation, it will be possible to determine their coordinates and angular diameter with a high degree of accuracy, to 1 minute of arc. The absence of an atmosphere on the moon makes the band of wavelengths from X-rays to radio waves accessible to investigation. One must also bear in mind that the moon lacks the background of radiation belt charged particles, which hinder X-ray studies in the vicinity of the earth.

If we know the Lunokhod's coordinates and the time of observation, we can compute the position on the celestial sphere of the point at which the X-ray telescope was aimed. Thus we can scan a strip the width of which is equal to the diameter of the field of view and the length of which is 12° of arc per day.

The principal task consisted in examining the diffuse X-ray background of space. The universe around us emits weak X-radiation. The origin of this radiation has not been definitely determined. It is believed that it originates in intergalactic space and that we only partially observe the luminescence of intergalactic gas heated to a temperature of several hundred thousand degrees.

It has been established that the universe has been expanding for the last 10 billion years. Distant galaxies are receding, with the speed of recession in direct relation to the galaxy's distance. What will happen in the future? Modern science assumes two possibilities: either the expansion of the universe will continue into infinity, or after 10-20 billion years it will begin to move inward again, a process which will terminate with the entire universe compressing into a single point. If the average density of the gas filling the universe is less than its critical density (approximately one atom of hydrogen per 100,000 cm^3 of space), the universe will continue to expand, but if it is greater than critical, then "contraction" of the universe will occur. One can assume that X-ray telescopes placed on the moon will help determine the density of gas in the universe and thus will help determine its ultimate fate.

The discovery of X-ray emissions from metagalactic objects has given astrophysicists and astronomers a powerful means of investigating the activity of celestial bodies -- perhaps the most magnificent process observed in nature today and which is possibly linked with new forms of existence and laws of transformation of matter.

Space Radiointerferometer

Of enormous importance for studying the far corners of the universe, densely populated by clearly-visible stars, galaxies and more difficult-to-observe pulsars, quasars and "neutron stars" is the resolution or resolving power of radio telescopes, that is the ability to determine the angular diameter of these celestial bodies. But their angular diameter is very small, and this makes it difficult to determine their precise location. Suffice it to say that it is less than 1 second of arc at a distance of 10 parsecs (a parsec is equal to 3.26 light years).

Resolving power is described by the ratio of emission wavelength to radio telescope diameter. The greater its diameter, the better it "sees." But as we have stated above, the size of terrestrial telescopes and radio telescopes can be increased only to reasonable limits, which have already been reached. Therefore astronomers and astrophysicists are compelled to perform "circuitous maneuvers," employing the so-called interference method. With this method observations of celestial objects possessing comparatively small angular diameters are conducted simultaneously with two radio telescopes located at a substantial distance from one another. Soviet and American scientists have employed such paired radio telescopes, so-called interferometers, in a joint deep-space experiment. Received radio signals would be simultaneously recorded on magnetic tape. These recordings would subsequently be compared and analyzed.

The dimensions of the earth do not permit an unlimited increase in distance between radio telescopes, and therefore terrestrial interferometers have already reached the limit of their capabilities. In addition, our planet's atmosphere not only introduces appreciable distortions into received radio signals but also does not permit observation throughout the entire electromagnetic spectrum.

Radio telescopes with received-signal amplifiers placed on the atmosphere-free moon and paired with terrestrial radio telescopes will make it possible to increase the distance between them to 400,000 km, which will increase their resolving power. Linked by radio and TV channels to terrestrial radio telescopes, they will become a unique radio-receiving system with very high resolution.

The Theory of Relativity

Half a century has passed since the formulation of the general theory of relativity, but the question of its experimental confirmation is just as vital today. According to this theory, material bodies influence the space around them with their mass. For example, a beam of light, which constitutes a flux of tiny particles -- corpuscles, when passing in the vicinity of massive bodies is attracted by them, and its path is deflected.

Precise calculations on the basis of the equations of general theory of relativity indicate that light from stars, passing close to the edge of the solar disk, should deflect from a straight line by approximately 1.75 seconds of arc (the angle at which a matchbox would be visible at a distance of approximately 5 km). The difficulties of astronomical observation of this effect are quite substantial, and an experiment can be performed only at the moment of a total eclipse of the sun, when the light from the stars is not lost in the incomparably greater solar luminosity.

Deviation of light rays from a straight line in the vicinity of the sun has been observed by astronomers on numerous occasions. According to observation data, the magnitude of deviation averages approximately 2 seconds of arc, that is somewhat greater than Einstein's theoretical calculations. The reason for the discrepancy with theory is not yet clear. From a lunar observatory it will be incomparably easier to determine the cause, since stellar point images are more distinctly visible in the lunar sky, while the absence of atmospheric refraction will make it possible to obtain more precise results.

The general theory of relativity states that during the motion of light in a gravitational field, its wavelength changes. If a photon emitted from the surface of a star reaches any other point in space with less gravitational potential, such as the earth, its emission wavelength will increase. This phenomenon is caused by the red shift, since the color red corresponds to the longest wavelengths of the visible spectrum. There can also occur a spectral shift toward the shortest wavelengths -- in this case the violet shift effect is observed: a photon coming from a point with less gravitational potential reaches a point with greater potential. This occurs, for example, to a photon emitted from the moon and received on the earth.

Initially the red-shift effect was discovered for the solar spectrum. In 1960 a group of British physicists tested this effect under terrestrial conditions. In both cases experimental data confirmed theoretical hypotheses. The observed red shift corresponded to the theoretically computed value with an accuracy of 4 percent. It will be possible to test this effect with even greater accuracy by placing special equipment on the moon.

Cosmology deals with the structure nad development of the universe. A decisive role among its scientific methods is played by spectral analysis of light emitted by stars and nebulae. In the spectra of almost all observed galaxies the lines indicating the various chemical elements have longer wavelengths than the lines of the same elements in the spectra of laboratory sources. In addition all lines in galactic spectra are shifted toward the red, longer-wave region.

It is assumed that this shift is caused by the Doppler effect, according to which when a wave source (sound, light, etc) moves relative to the observer, there occurs a wavelength shift. Imagine that you are standing on a railroad platform. An approaching locomotive blows its whistle. The sound of the whistle rises, with the frequency of the tone dependent on the train's speed. But when the train passes by, the frequency changes abruptly -- it becomes lower, with the rate of change directly dependent on the speed of the receding train.

When a moving light source is approaching the observer, the frequency of the light wave rises, since at a given moment the observer is receiving an increasing number of waves. When the light source recedes from the observer, the latter receives a decreasing number of waves. The drop in light wave frequency is accompanied by a shift toward the red end of the spectrum, while an increase in frequency is accompanied by a shift toward the violet region. This effect, called the Doppler effect after the Prague mathematician who explained it, is manifested more strongly with a greater relative speed between source and observer and with a higher light wave frequency.

In the enormous expanse of the universe accessible to observation, sources of luminous radiation appear to be receding from us at a very high rate of speed, the magnitude of which can be determined by the red shift. This fact has caused scientists to draw a conclusion of immense scientific significance: the red shift of the galactic spectra is due to movement by the galaxies along the line of sight -- toward us or from us. The same conclusion under certain circumstances proceeds from the general theory of relativity. With the assistance of quantum light generators placed on the moon and on the earth it will be possible to obtain one more experimental confirmation of the galactic spectra red shift effect.

Recently it was reported that American scientist D. Weber had succeeded in recording a gravitational wave in space. This exciting news is one more experimental confirmation of the correctness of the general theory of relativity. In 1916 Albert Einstein, the author of this theory, expressed the assumption that the gravity fields of celestial bodies should emit gravitational waves. But since the energy of these waves is extremely low, it is very difficult to detect them. Even such a giant of the solar system as Jupiter generates gravitational radiation of only 450 watts in its motion around the sun. Just try to distinguish the light emitted by a 500 watt bulb at such an enormous distance! This planet's disk is no brighter than a dull star.

Only very massive objects generate fairly strong gravitational waves. These waves are generated by the collapse of stars -- their ultradense compression under the effect of the enormous force of gravity, as well as in the rotation of neutron stars -- "white dwarfs." Weber used the earth as an antenna to pick up gravitational waves from deep space. The scientist figured that this massive body should pulsate from gravitational waves. To record the oscillations Weber placed thousand-kilogram aluminum cylinders in vacuum chambers insulated from ambient vibrations. Two such cylinders were placed at a distance of 1000 km from one another (one was located near Washington and the other near Chicago). Weber believes that the earth's gravitational oscillations should generate resonant oscillations in the cylinders. There exist a great many causes, however, which can randomly produce the anticipated difference in potentials. Nevertheless it is highly improbable that such a difference would occur simultaneously on two detectors located so far from one another.

Coinciding oscillations (which were observed at least 10 times during the 3-month period of the experiment) could also have been caused by other factors, such as by ground vibrations or electromagnetic radiations from the oscillating cylinders. Random electromagnetic waves caused great difficulties to the experimenters. Although their intensity was evidently very low: the cylinders were carefully shileded -- even very small disturbances could nullify the entire experiment. Weber concluded that the problem could be solved if the cylinders were placed both on the earth and on the moon. By comparing their readings, it will be possible to determine with greater accuracy not only the velocity of the gravitation waves but also their strength and direction.

American scientists intend to place on the moon a special gravitational wave detector. Detection of such waves will be of no less scientific and practical significance than the discovery of radio waves. Some scientists believe that gravitational waves propagate practically instantaneously. One can easily imagine the enormous significance of gravitational wave communications for interplanetary spacecraft, and in the more distant future for interstellar spaceships as well.

Let us recall the history of the discovery of electromagnetic waves. Their existence was predicted by James Maxwell. They were first detected by Gustav Hertz and practically utilized by A. Popov. A new area of astrophysical investigations -- gravitational investigations -- will develop with the discovery of gravitational waves. This area of inquiry will substantially add to the information provided science by optical, radar, X-ray, gamma-quantum astronomy and astrophysics.

Light Tool

Spaceships cruise as tiny, invisible grains of sand among the stars, across the boundless expanses of the universe. They cannot be seen even with the finest telescopes. Only radio waves link them with earth, but at times, when the craft pass through extensive zones of ionized gas, radio-wave communications are interrupted. Then the spaceship lasers go into operation. They send to earth needle-thin but extremely powerful beams of light rays. Thanks to lasers it is possible not only to maintain voice communications with interplanetary spaceships but also to spot them visually at enormous distances.

There exist several laser designs employing solid minerals, liquids and a gaseous medium to produce beam of light. We know from quantum mechanics that the atoms and ions of solid, liquid and gaseous matter serve as unique energy storage cells. They possess the capability of radiating and absorbing energy in strictly-specified portions -- quanta. In order for an atom to release a quantum of energy, it must be "excited," that is it must be imparted excess energy. This energy is imparted to it by an electromagnetic field created by an auxiliary booster or intensification generator. Particles of quantum generator (laser) materials, having absorbed a specific dose of generated energy, transition to a higher energy level. Under certain conditions the atoms release stored energy in the form of electromagnetic radiation which is strictly coordinated in phase and frequency.

A group of people is standing on a river bank, waiting for a ferry and conversing. If one individual calls out to the ferryman, his voice may be drowned out among the other voices. But if all shout simultaneously, the sound will be many times more powerful, and it will carry to the other bank. A like coordination occurs among the excited atoms in a quantum generator. This makes it possible to produce a narrow beam of parallel waves of identical wavelength. The brightness of such a beam may be a million times greater than that of the sun, while the light pressure may reach several million standard atmospheres.

In order to illuminate an area 1 km^2 on the earth's surface with a laser beamed from the moon, a laser gun with a diameter of only 20-30 cm will be required. Such a gun can also be fired into space. But for what purpose? We know that the greater the distance between two radio transmitter and receiver sites, the more precisely the transmitter antennas must be used in order to generate sufficient signal voltage at the receiver input. But there is an inexorable law in physics: radiation power, be it visible light or radio waves, diminishes proportional to the square of the distance. Therefore in order to maintain reliable communications with interplanetary spacecraft it is necessary to possess not only highly-directional antennas but also powerful transmitters and extremely sensitive receivers.

In order to concentrate the energy radiated by a radio transmitter, to gather it into a narrow beam and thus to increase its density at the point of reception, special highly-directional parabolic antennas are employed at both ends, on earth and on board spacecraft. Ground parabolic antennas sometimes are quite large. For example, the reflector diameter of one of the largest radio telescopes is 76 m, the radio telescope itself weighs 2000 tons, and its concrete base weighs 10,000 tons. Designs are on the drawing boards for radio telescopes of even greater resolving power, with an antenna diameter of 250-300 m. But for any given wavelength there is a limit to antenna dimensions. It has been calculated that for a wavelength of 3 cm a parabolic antenna diameter should be 150 meters. Nor can transmitter power be infinitely increased, because the electrical properties of the earth's atmosphere substantially affect the passage of radio signals.

Unmanned spacecraft sent to the moon, Mars and Venus are equipped with special parabolic antennas about 2 meters in diameter, which produce a highly-directional radio beam. If we take into consideration the fact that the beam of radio waves emitted by such an antenna will become narrower as the antenna diameter increases, and that with increasing distance increasingly highly-directional radiation is required, the need to increase the size of these antennas will become quite obvious. But the larger the antenna, the more difficult it is to accomodate it on a spacecraft.

Lasers, which are extremely small devices, make it possible to form powerful beams of highly-directional light emission, thus achieving incomparably greater range of communication between spacecraft and the earth. Lasers will have a potential effective range of billions of kilometers. If one considers that a practically inexhaustible stream of solar energy can be used to generate radio and light emission in space, particularly on flights to Mars, Venus, and Mercury, and if one considers the small size and weight of lasers, their advantages over other means of space radio communications will become quite obvious.

With the aid of lasers it will be possible to measure the distance between spacecraft in flight, their altitude and velocity above the surface of a planet. We shall note that accuracy in measuring speed with an 18-meter diameter radar mounted on a spacecraft when landing on the moon is 2000 times less than that which a Doppler navigation system is capable of with a laser beam with a 60 cm diameter optical system. Lasers can also be used as navigation beacons. Special devices to detect light signals can be mounted on the outside of a spacecraft. Response light signals would be emitted upon receiving them.

The highly monochromatic laser light beam is an excellent transmitter of information. With the aid of space laser stations it would be possible simultaneously to transmit approximately 1 billion telephone conversations or several thousand television channels. The shorter the wavelength, the higher the frequency of electromagnetic oscillations. At a wavelength of 300 meters the frequency is 1 million oscillations per second, while at 3 meters it is 100 million per second. Light waves are at a frequency of hundreds of million and even billion Hertz. The higher the wave frequency, the greater the number of elementary signals which can be transmitted per unit of time.

The precise directivity and high power of a laser source enable it to be utilized as a means of light ranging of celestial bodies. The power of a radio signal transmitted by a radar and received upon reflection from the ranging target is attenuated proportional to the distance to the fourth power. Extremely powerful transmitters and highly-sensitive receivers are required for space radar uses! The power of the radio transmitter employed by Soviet radio physicists to range Venus was 250 million watts, while the received reflected signal was approximately 100 billion times less than one billionth of one billionth of the power of a table lamp. A receiver must be extraordinarily sensitive to pick up such an infinitesimal amount of radiated energy.

Lasers will make it possible to build even more sensitive receiving equipment. Utilization of lasers in radio telescopes, radars and other electronic devices will make it possible substantially to increase the effective range of this equipment. Thanks to lasers it will be possible to observe celestial bodies of low radio and visual luminance, the emissions of which have not yet been detected. While utilization of laser devices on earth for these purposes is made difficult by the diffusion of light in the atmosphere, the potential of light ranging of celestial bodies from the surface of the atmosphere-free moon is truly fantastic.

Due to the broad antenna directivity range, conventional radars are unable to differentiate objects located close to one another. Lasers will give them excellent resolving capacity. They will make it possible to receive an image of the surface of celestial bodies with a clarity and precision unattainable by any other means, to map the surface more accurately and to solve many scientific problems connected with the structure and motion of celestial bodies.

Laser Bridges

The first experiments in lunar laser ranging were conducted by U.S. and Soviet scientists in 1962-1963. The principal aim of these experiments was to determine the precise distance between the earth and the moon. A laser beam was aimed at the moon. Reflecting from the lunar surface, it returned to earth, where it was received by a special receiving device. The pulse duration was approximately one thousandth of a second. Distance to the moon was determined on the basis of the speed of light and time of pulse passage from the earth to the moon and back. The distance was computed with an accuracy of down to 150 km. Subsequently, with the employment of laser light sources with a pulse duration of approximately one one hundred millionth of a second, it became possible to determine distance to the moon with an accuracy of down to several hundred meters.

For several centuries scientists endeavored to understand the laws of lunar motion. A satisfactory theory of this motion, designed for practical purposes -- for predicting lunar motions -- did not appear until the beginning of this century. It was based on Newton's universal law of gravitation. It includes a number of basic parameters of the earth-moon system as so-called integration constants. But since the basic parameters of the earth-moon system: distance between them, radius of the lunar sphere, etc -- were determined with limited accuracy, the certainty of the theory proper proved inadequate. For example, astrometric characteristics of the moon's orbit were determined by means of goniometric observations of various points on the lunar surface at various positions of the moon relative to the earth. But since the measured angles were small, the obtained results were not very accurate. The mean distance between the centers of mass of the moon and the earth (mean orbital radius) was measured, for example, with an error of 3-4 km. The shape of the moon was studied essentially with stereophotogrammetric methods, by interpreting the stereoscopic effect of a pair of photographs of the moon taken during various librations. The accuracy of measurement of the lunar radius pointing toward the earth ("frontal radius") was ±4-5 km. There were also errors of several kilometers in the coordinates of various points on the lunar surface relative to the earth. It became obvious that it is impossible to improve the accuracy of these constants employing the goniometric method.

Optical ranging of the moon made it possible to perform measurements with a higher degree of accuracy. But there were difficulties here as well. The first consisted in the fact that a light beam would substantially attenuate on the way to the moon and back. Upon returning to the laser receiver its strength would be 10^{20} times less than initially. In addition, the moon-reflected signal carried dozens and hundreds of photons, which were not easy to distinguish on the background of various interference.

Another difficulty was more fundamental in nature. Due to multiple scattering during passage through the earth's atmosphere, the light beam would undergo deflection. In spite of the fact that its components were initially precisely parallel, upon exiting from the atmosphere its aperture angle would be 2-3 seconds of arc. The spot of light corresponding to this divergence had a diameter of 3.5-5 km on the lunar surface. If it fell on an uneven surface, the error in range would be defined by the relative elevations involved. The moon's spherical shape led to an additional "blurring" of the reflected pulse, which would increase with increasing distance of the reflection point from the center of the lunar disk. The ranging target would acquire a certain spatial depth, which would lead to a distance measurement error of hundreds of meters and sometimes several kilometers.

Scientists were able to eliminate all these difficulties to a substantial degree, by placing special reflectors on the moon which would ensure an aimed reflection of the laser beam back to the earth. Constituting a point target, they would reduce the "blurring" of the reflected signal and thus would make it possible to measure more precisely distance to the target.

There are four such reflectors on the moon, made by U.S., Soviet and French scientists. The laser reflector designed by the French scientists, for example, comprises a panel containing 14 tetrahedral prisms. Each prism has the appearance of a corner cut from a cube in such a manner that three of its angles are right angles. If a beam of light is focused on the cut plane, which is the prism's entrance facet, after a triple internal reflection within the prism it will reemerge in the direction of the incident beam. The ability of the prism to reflect light precisely in the reverse direction is retained only if its right angles are maintained with an accuracy of one tenth of a second of arc. The reflector weighs 3.7 kg.

The system includes a ruby laser optical modulated-Q transmitter with a pulse duration of one one hundred millionth of a second, a narrow-band photoreceiver with a reflected-signal recording system, a device to measure light signal propagation time to the reflector and back with a measurement accuracy of 1 one hundred millionth of a second, automatic control units and equipment controls.

Laser moon ranging from the Soviet Union was performed at the Crimean Astrophysical Observatory with the aid of a telescope with a 2.6 meter mirror, and in France from the Pic du Midi Observatory with the aid of a 1-meter telescope.

In December 1970 Soviet scientists conducted the first successful laser ranging experiment with the French laser reflector, the useful life of which, according to information in the French press, is figured at 10 years. The telescope functioned as a giant searchlight, beaming toward the moon every 15 seconds a 300 megawatt light pulse. The reflected, highly attenuated signal returned to the telescope mirror. The light pulse duration was 1 one hundred millionth of a second. Time of light passage to and from the target was recorded with an equal degree of accuracy. Knowledge of the speed of light made it possible precisely to compute distance to the target.

Individual photons would be received by the narrow-band photoreceiver. It is true that in addition to useful signal luminous radiation from the moon and stars was also present at the receiver input. This radiation was "superimposed" on the useful signal and generated interference analogous to the lightning-discharge interference in a radio receiver. If one considers that a photoreceiver which receives only a few photons can achieve a high degree of accuracy in measuring distance to the target, the difficulties in measuring time of light signal propagation from the telescope to the reflector and back will become quite obvious.

Additional difficulties lie in the fact that the laser beam on the moon's surface illuminates a spot several kilometers in diameter, but only that small portion of the light rays striking the reflector will return to earth. Back on earth, from a spot of reflected light approximately 10 km in diameter, we can receive only a dot of light the size of the receiving telescope aperture. Hence the obvious advisability of utilizing large-diameter telescopes with a special recording device.

The immediate result of the ranging operation is high-precision measurement of the distance from the terrestrial observation point to the surface of a celestial body. The distance per se is not of any particular value, but being linked with other characteristics (size and shape of the celestial body, character of its orbital motion and internal structure), it can help reach conclusions of fundamental importance. For example, "shooting" at reflectors located in different parts of the lunar surface with terrestrial lasers will make it possible to perform highly-accurate geodetic and geodynamic measurements of the earth-moon system and on this basis to increase the accuracy of its principal parameters by approximately two orders of magnitude, to investigate the moon's rotation and libration, its shape, and thus to increase the accuracy of determination of the position of any point on the earth and moon, as well as to study in detail such fundamental characteristics of the earth as its rate of rotation, the motion of its poles, and continental drift.

Why is this necessary? We know that the earth does not rotate uniformly on its axis. Astronomers have studied this irregularity by means of star observations. The method of laser triangulation between terrestrial observatories and reflectors located on the moon will make it possible to record the earth's rotation with a high degree of accuracy.

For more than 70 years now astronomers and geophysicists have carefully observed the motion of the earth's poles, endeavoring to tie the peculiarities of this motion in with various phenomena on and under the earth's surface. At the International Astronomical Union congress held in England in August 1970, there was a lively debate on whether earthquakes influence the motion of the poles. Unfortunately due to a lack of precise data, astronomers are still compelled to average data on the motion of the poles, whereby slight deflections are smoothed or ignored entirely. This will not happen if we can obtain data on the motion of the poles with the aid of precise measurements of distances from various points on the earth's surface to the moon. In this way we can find a new means of solving one of the most urgent problems of geophysics -- the problem of earthquake forecasting.

At the end of the sixties scientists proceeded to draft an international program for the study of continental drift. According to present theories, not only small depressions such as Lake Baikal but entire oceans, such as the Atlantic, were formed as a result of the separation of continents. Geophysicist Alfred Wegener's hypothesis of continental drift is well known. As early as 1920 he drew attention to the similarity between the coastlines of Africa and Europe on the one hand and those of South and North America on the other. Examination of a map shows how the coastlines "fit" almost perfectly. Wegener hypothesized the existence at some time in the past of a single supercontinent which was split into several pieces, which drifted apart. At one time this question was debated on the pages of professional and popular-scientific journals. The hypothesis was not bolstered with sufficiently convincing proof, and it was forgotten. We have now returned to it. Many years of observations have shown that the continents are moving away from one another at a rate of 2-4 cm per year. Over a long period of time this can substantially alter the face of our planet. Wegener believed that under the continents the earth's granite and basalt crust was approximately 100 kilometers thick and that the crust floated on underlying more basic rock, containing less silicon and rich in magnesium, which are in a molten or plastic state. The continents float on this underlying rock like icebergs in the Arctic and Antarctic. Recently-conducted seismic investigations have confirmed the fundamental possibility of Wegener's hypothesis. We must assume that the lunar laser ranging method will be quite helpful in testing this hypothesis.

Imagine that a gigantic triangulation tower has been constructed on the earth, with the moon mounted on the top. If it is visible at the same time from different continents, such as from Europe and North America, then by beaming laser beams simultaneously at a specific point on the lunar surface, we can measure the angle between them. Knowing this angle and the distance to the moon, we can measure with a high degree of accuracy the horizontal distance between two mutually-distant points on the earth's surface.

It is true that we cannot determine continent movement with one measurement alone. But if measurements are conducted during the course of several years, it will be possible to determine with considerably greater accuracy whether the distance between these points has changed by even a few centimeters, that is we can determine whether North America is receding from Europe. All this information will be of primary importance in elaborating a general theory of crustal deformation. It will help verify the hypothesis of the forming of continents and oceans on the earth. If it is established that North America is in fact receding from Europe, this will confirm the view that the Atlantic Ocean is comparatively young, secondary, that it was formed as a consequence of the splitting of a larger landmass and is gradually widening due to the westerly displacement of the North American continent.

In recent years much interesting information has been obtained on the ocean floor. We have learned that there are at least 10,000 volcanoes in the Pacific alone, more than on all the landmasses. The longest and densest chains of volcanoes are found on the mid-ocean ridges. In the opinion of some scientists, in the area of the mid-ocean ridges the crust is separating, and mantle material is slowly rising to the surface or is being extruded in the form of volcanic lava flows. At the 15th General Assembly of the International Geodetic and Geophysical Union, held in Moscow in the summer of 1971, a resolution was passed calling for a joint scientific project to be conducted in the next decade, involving the participation of scientists from many countries within the framework of the international "Geodynamic Project," the basis of which will be the hypothesis of the spreading of the ocean floor. It assumes the following model of processes deep within the crust underlying the ocean: material is rising upward in the area of the mid-ocean ridges and is then spreading outward along their slopes, pushing back the older rocks, which in turn plunge under the continental plates. There is no doubt that laser ranging techniques will greatly assist investigators in their study of this complex process.

There exists a theory which explains continental drift in terms of lunar influence. Due to tidal friction the earth's outer layers are retarded in relation to the earth's interior, and this causes a drifting of the earth's crust around the core. Island chains drawn out in the shape of semicircles or arcs are allegedly evidence in favor of this explanation. These island chains include the Japanese, Kurile and Aleutian Islands. As a rule they bulge eastward or southward, but never westward. Perhaps the moon indeed plays the role of a brake and pulls along certain masses.

We know that the moon causes tides. Tides produce friction which acts on our planet like a giant brake. The earth's rotation is slowing and the day is becoming longer -- the earth is losing angular momentum. According to the law of conservation of energy, this energy cannot disappear in closed systems but is merely redistributed. The earth's angular momentum is being absorbed by the moon, the latter's orbital radius is increasing, and it is gradually receding from the earth. If precision measurements establish that the distance between the earth and moon is in fact increasing, we can consider this hypothesis to be correct.

Many scientists believe that earthquakes are closely linked with the rocking of the earth's axis which occurs during new moon and full moon, when the gravitational interaction of the earth and moon is at a maximum. Rocking of the earth's axis can be established with the aid of laser devices placed on the moon.

We know that the earth's crust consists of a number of platforms or plates which are in continuous motion. With the aid of laser devices we can track vertical displacements of the earth's crust; for example, we can determine whether a given terrestrial mountain range is rising or subsiding. Laser tracking of the movement of individual crustal plates will make it possible to predict with a high degree of accuracy what will occur when these plates come into contact. Will one override the other or will they collide -- the earth's crust will wrinkle, forming folds. The supporters of this hypothesis have gathered a sufficient number of facts together to examine the possibility of horizontal movements of continents as a serious scientific problem. It is true that this hypothesis also has many opponents. It is not surprising that this hypothesis is the subject of sharp debate: many aspects of earth science, including questions pertaining to the formation of deposits of commercially valuable minerals, are tied together in a single bundle.

Enormous possibilities for laser ranging of celestial bodies will open up with placement on the moon of telescopes equipped with powerful lasers and linked with laser reflectors located on other celestial bodies: the planets and their moons, large asteroids and some comets. It is very difficult for a ray of light to penetrate the earth's atmosphere. Clouds and fog, dust and smoke, the many substances present in the atmosphere greatly attenuate a light ray. The difficulties connected with laser ranging celestial bodies from earth become quite obvious if we consider the fact that the laser beam must pass through the earth's atmosphere twice. Highly-precise measurements of distances from several points on the earth's surface to a system of points on the lunar surface may become a method of solving diversified problems of fundamental scientific importance.

Laser light sources can be utilized, for example, to transmit energy from the moon to spacecraft traveling the expanses of the solar system, for energy attenuation does not occur in space. Since not electrons but photons take part in the energy transmission, it can be transmitted considerable distances. Lasers may also be successfully employed in accomplishing such a magnificent scientific task as communication with extraterrestrial civilizations.